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Technical Memorandum

To: Bill Johnson, MDNR
From: Tina Pint and Jeré Mohr
Subject: Response to Cooperating Agency Comments Mine Site MODFLOW Model – Version 2
Date: July 7, 2015
Project: NorthMet EIS (23690862.00)
c: Jennifer Saran, PolyMet

This memorandum addresses two sets of comments and questions that have recently been raised on the NorthMet Mine Site MODFLOW model developed in support of the PolyMet NorthMet FEIS: (1) the simulation of the Peter Mitchell pits (PMP) in model calibration and predictive simulations; and (2) the simulation of the Partridge River. Each of these topics is addressed below, along with calculations to confirm the pit inflow estimates from the MODFLOW model.

1.0 Peter Mitchell Pits and Calibration

1.1 Simulation of the Peter Mitchell Pits

Questions have been raised about how the location, shape, and elevations were determined for the simulation of the Peter Mitchell pits. In the MODFLOW model, the Peter Mitchell pits are modeled using constant head cells to represent the mine pit lakes. The location of the pit lakes were based on the 2003 aerial photo of the PMP. Heads for the pit lakes were assigned based on data from the DNR Mesabi Elevation Project, which was from 1996. More recent analysis completed for Reference (1) indicated different pit lake locations and elevations than those used in the MODFLOW model. However, the data sources used for the MODFLOW model represented the available information at the time of original model development.

The decision was made in the early stages of the MODFLOW modeling to not attempt to simulate changing conditions at Peter Mitchell given the conceptual model for the site, and for the reasons presented in Reference (1) about the expectations for groundwater conditions as a result of Peter Mitchell pit dewatering. This decision was not commented on during the DEIS public review period, the IAP process, or the SDEIS public review period. The MODFLOW model underwent several phases of review, which included consideration of whether to simulate multiple Peter Mitchell Pit lake elevations during review of Draft 03 of RS22 Appendix B. Given that the MODFLOW model's primary objective was to provide estimates of mine pit inflows (as opposed to simulating the hydraulic interaction—or lack thereof—between the Peter Mitchell Pits and surrounding surface water and groundwater), assessing alternate Peter Mitchell Pit elevations was not relevant.

1.2 Selection of Calibration Conditions

A comment was made by John Coleman (GLIFWC) that there is a hydrologic linkage between the Peter Mitchell pits and the Partridge River (not including direct NPDES discharges) and thus, using water levels in the PMPs that coincide with the time period represented by the baseflow estimates is important for the MODFLOW model calibration. This section describes that the selected MODFLOW model calibration conditions for the Mine Site MODFLOW model are appropriate, including the representation of water levels in the PMPs.

The Mine Site MODFLOW model was developed and calibrated to existing conditions at the NorthMet Mine Site. For this purpose, the average water level data collected between 2005 and 2013 in wells located in the surficial aquifer and bedrock were determined to be representative of existing conditions and were used as calibration targets. Likewise, it was determined that groundwater baseflow estimates of 0.41, 0.51, and 0.92 cfs at SW002, SW003, and SW004, respectively (based on XP-SWMM modeling of the Partridge River basin), are representative of existing conditions and should be used for model calibration.

The Partridge River baseflow values used as input in the calibration targets in the MODFLOW model are based on the average 30-day low flow at USGS gage 04015475 observed from water years 1979 through 1988. The average value observed at the gage during the 10-year period was extrapolated upstream using the relative results of the XP-SWMM model run for the same period (i.e., comparing the modeled 30-day low flow at the location of the gage and at the location used for MODFLOW calibration) and a scaling factor based on the period when there was no dewatering from the PMPs to the Partridge River (water years 1978 and 1988). This method is described in Section 4.4.1.3 of the Water Modeling Data Package - Volume 1 Mine Site (Reference (2)).

The XP-SWMM model was calibrated/validated to observed data located approximately 15 miles downstream of the Peter Mitchell pits and returns an average baseflow estimate at each modeled location based on a continuous 10-year modeled period. The 10-year period is used to represent average hydrologic conditions, as opposed to a specific period in time or water level in the Peter Mitchell pits. That is, the baseflow estimate used in the MODFLOW model calibration does not represent a specific time period (such as 1986-1988). During the 10-year calibration period, there were varying conditions at Peter Mitchell pit, which are thus captured in the baseflow estimate. The inputs to the XP-SWMM model do not include water levels in the Peter Mitchell pits or groundwater contributions from the PMP watersheds. Although seepage between the PMPs and the Partridge River may have affected the observed data (and thus the XP-SWMM model calibration target), the XP-SWMM model was validated against the observed gage data, as well as the gage data adjusted to remove the influence of PMP dewatering to the Partridge River, with similar results (see Section 4.4.1.2.6 of the Water Modeling Data Package - Volume 1 Mine Site (Reference (2)). This suggests that water levels in the PMPs have negligible impact on the XP-SWMM model calibration. Recent changes in pit-lake water levels at Peter Mitchell have likely had no impact on

Partridge River baseflow because the surficial aquifer is already at a maximum degree of dewatering (because pit water levels have been below the unconsolidated/bedrock interface for a substantial period of time) and bedrock hydraulic conductivity is low (Section 4.3.3.2 of Reference (2), Reference (3)), limiting the spatial extent of drawdown in bedrock. This method is representative of existing and future conditions for the purpose of the NorthMet Mine Site MODFLOW model (Reference (4)).

1.3 Modeling Different PMP Conditions

The MODFLOW model was primarily designed to predict groundwater flow rates to the NorthMet mine pits, and was also used to evaluate groundwater flow directions for definition of GoldSim groundwater flow paths. The model is well-suited and appropriate for these purposes. The existing MODFLOW model was calibrated to groundwater levels near the NorthMet site and to Partridge River baseflow. In this model the pit lake stages at Peter Mitchell Pit are higher than currently exist. If the existing model is modified, as was done by John Coleman (GLIFWC), to simulate either current conditions or planned closure conditions (a pit lake of 1500 feet MSL at Peter Mitchell), the model suggests that a large amount of drawdown would be induced, baseflow to the Partridge River near the Peter Mitchell Pit is eliminated, and flow in the bedrock occurs from the NorthMet project to the Peter Mitchell Pit. As noted previously, however, the MODFLOW model was neither developed nor calibrated to simulate these conditions. For reasons discussed below, this exercise is not appropriate and demonstrates that these predictions, that the model was not designed to make, are not reliable.

Review of pit and lake levels near the dewatered Peter Mitchell pits suggests that any depressions in groundwater levels that may have developed around the dewatered pits have not been significant enough to result in changes in water levels in adjacent pit lakes and natural lakes (Section 2.1 of Reference (1)). The MODFLOW model was not intended to be used to evaluate effects of dewatering at the PMP. Prior to using a model to answer questions other than those that it was specifically designed to answer, the model inputs and assumptions should be evaluated to determine whether the model is appropriate for answering the alternative questions. When the MODFLOW model—or any other model—is used in a manner other than what it was intended to model, predictions generated by the model may no longer be reliable. So while the use of the existing MODFLOW model for its intended purpose is still fully appropriate, it should not be used for unintended purposes.

2.0 Confirmation of MODFLOW Model

The groundwater models developed in support of the NorthMet EIS were designed with specific predictive purposes that were well-defined, and the models remain appropriate for those purposes. The primary purpose of the Mine Site MODFLOW was to estimate groundwater inflow rates to the NorthMet mine pits. Analytical methods used to validate these Mine Site MODFLOW model predictions are described below. The analytical method was used to answer two questions:

1. Given field-measured / estimated hydraulic conductivity values, how do the analytical pit inflow estimates compare with the MODFLOW estimates?
2. Given the hydraulic conductivity values obtained from the MODFLOW model calibration, how do the analytical pit inflow estimates compare with the MODFLOW estimates?

2.1.1 Confirmation Methodology

Groundwater inflow rate predictions from the existing MODFLOW model have been confirmed by independent analytical calculations. Analytical equations for estimating groundwater inflow to a mine pit, described in Marinelli and Niccoli (Reference (5)), were applied to the proposed NorthMet mine pits when they are at the maximum extent (Year 11 for the East Pit and Year 20 for the West Pit). The equations describe steady-state, radially-symmetric groundwater flow both laterally through the pit walls, and vertically through the pit bottom. While a number of simplifying assumptions were required for the analytical calculations, the inflow estimates obtained provide a baseline range appropriate for comparison with the estimates obtained from the MODFLOW model.

Figure 1 illustrates the conceptual model presented by Reference (5). As shown, the aquifer around the pit is divided into two zones, each governed by a different set of assumptions. The pit itself is generalized as a right circular cylinder, and the first aquifer zone (shown as "Upper Zone" in Figure 1) is adjacent to the pit laterally; it extends from the ground surface to the bottom of the pit. Within this zone, groundwater flow is assumed to be horizontal. Recharge is applied uniformly across the top of the zone, simulating infiltration. The second aquifer zone (shown as "Lower Zone" in Figure 1) is located below the pit and the Upper Zone; the two aquifer zones are divided by a no-flow boundary. Within the Lower Zone, groundwater flows both horizontally and vertically.

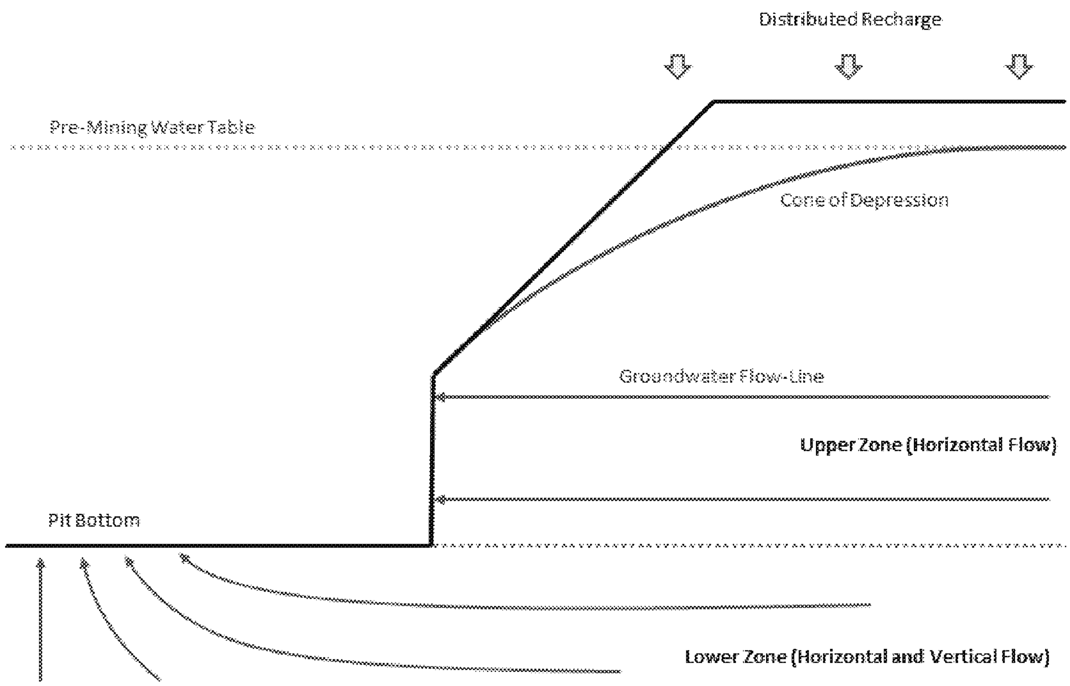

Figure 1 Pit inflow general conceptual model

The conceptual model and equations described by Reference (5) and Figure 1 were implemented in this analysis with one important modification: the Upper Zone laterally adjacent to the pit was divided into two zones, an upper zone representing unconsolidated deposits and a lower zone representing bedrock. Each zone was assigned its own recharge rate, hydraulic conductivity, and saturated thickness, and a radius of influence was calculated for each zone. The conceptual model, as modified for this analysis, is presented in Figure 2. Calculating total inflow to the pit involves summing the calculated inflow from each aquifer zone. Conceptually, the three-zone approach better represents the real-world system: the Upper Zone consisting of two distinct zones: an zone of relatively thin, unconsolidated deposits with high hydraulic conductivity, underlain by a zone of bedrock that is thicker and has a lower hydraulic conductivity relative to the unconsolidated deposits; and the Lower Zone beneath the pit consisting of bedrock. Hydraulic conductivity data collected onsite indicates that the upper portion of the Virginia Formation is approximately 3 to 5 times more permeable than the lower portion (Reference (3)). For the pit inflow calculations, the hydraulic conductivity of the Virginia Formation in the Lower Zone was assumed to be equal to the hydraulic conductivity of the Virginia Formation in the Upper Zone divided by three. For the East Pit calculations, half of the pit was assumed to consist of Virginia Formation (hydraulic conductivity of the Upper Zone ranging from 2.4×10^{-3} feet/day to 6.8×10^{-1} feet/day) and half was assumed to consist of Duluth Complex (hydraulic conductivity ranging from 2.6×10^{-4} feet/day to 4.1×10^{-2} feet/day). Two sets of calculations were run for each parameter combination, one assuming all of the bedrock was Virginia Formation and the other assuming all of the bedrock was Duluth Complex. The total inflow to the

East Pit was obtained by summing the unconsolidated contribution, half of the all Virginia Formation contribution, and half of the all Duluth Complex contribution.

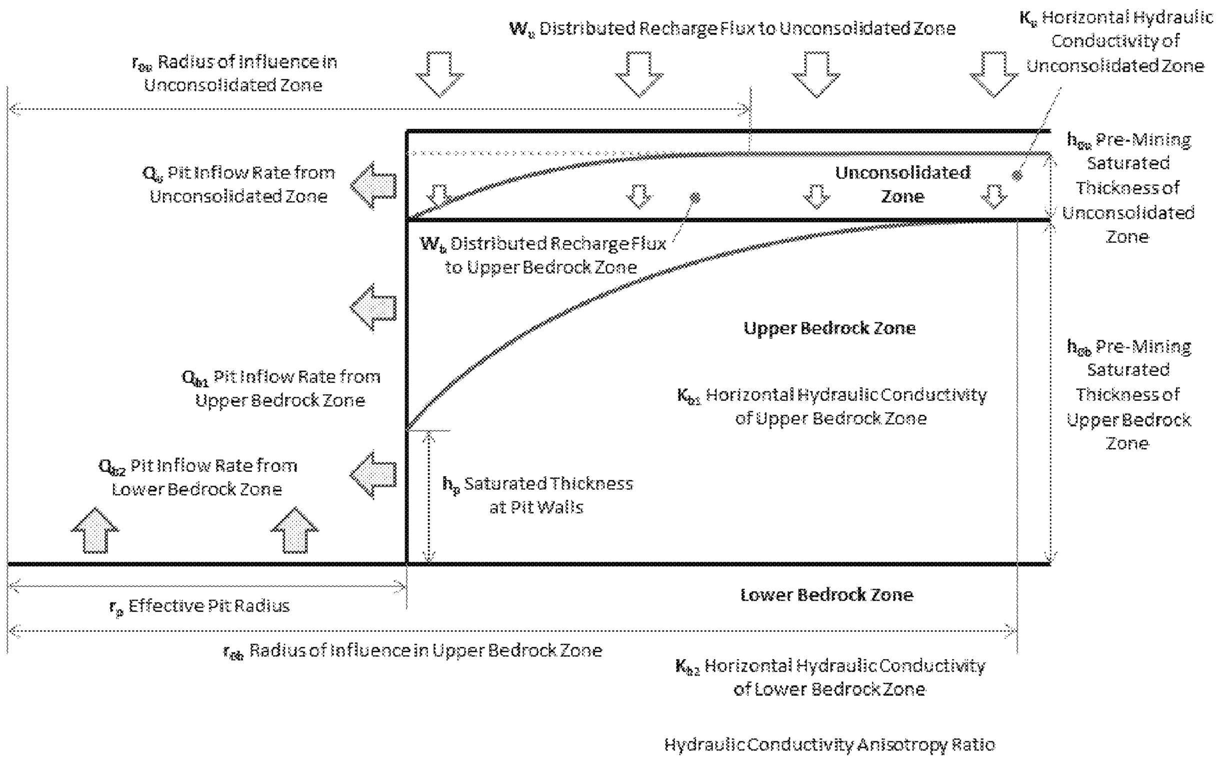

Figure 2 Pit inflow modified conceptual model

The analysis was completed using multiple values for selected parameters to obtain a range of inflow estimates. A minimum, maximum, and best estimate value was selected for selected parameters. The pit inflows were calculated with each parameter adjusted from its baseline value separately, with the remaining parameters kept at their baseline values. Two sets of calculations were run – one set used field estimates of hydraulic conductivity to establish the best estimate hydraulic conductivity value and a second set using the calibrated hydraulic conductivity values from the MODFLOW model as the best estimate hydraulic conductivity values. The resulting pit inflow estimates were combined to establish the overall range of pit inflows. Large Table 1 summarizes the values for the input parameters shown on Figure 2 and provides the basis for the values. Note that the radius of influence in the unconsolidated zone (r_{0u}) and radius of influence in the upper bedrock zone (r_{0b}) are calculated for each set of input parameters and are not shown in Large Table 1.

2.1.2 Confirmation Results

Results using the analytical equation are compared to the results from the MODFLOW model in Table 1, below, as well as the values used in the GoldSim model. The results from the MODFLOW model are used in the GoldSim model, along with a degree of uncertainty (see Section 5.2.2.6.3 of Reference (2)). The uncertainty in the MODFLOW model predictions that is applied in the GoldSim model is also shown in Table 1 as minimum and maximum values. The analytical method uses simplifying assumptions and does not capture all of the complexity that is included in the MODFLOW model. However, for the two examples presented here (West Pit at Year 20 and East Pit at Year 11) it provides a good confirmation of the MODFLOW model predictions.

Table 1 Comparison of groundwater inflow rates at maximum pit extent

		Minimum (gpm)	Average (gpm)	Maximum (gpm)
West Pit Year 20	MODFLOW	--	40	--
	GoldSim	29[1]	40	89[1]
	Analytical Calculation – K based on field data	25	40	155
	Analytical Calculation – MODFLOW K values	10	80	340
East Pit Year 11	MODFLOW	--	760	--
	GoldSim	543[1]	760	1651[1]
	Analytical Calculation – K based on field data	30	432	1517
	Analytical Calculation – MODFLOW K values	70	690	1560

(1) Value represents the 1st or 99th percentile value used in the GoldSim model, which is essentially equivalent to a minimum or maximum value.

The pit inflow estimates presented in Table 1 were developed using the assumption that 90% of the total recharge flux is applied to the unconsolidated deposits and 10% is applied to the bedrock. To evaluate the sensitivity of this assumption, an additional set of calculations was run assuming that 50% of the total recharge flux is applied the unconsolidated deposits and 50% is applied to the bedrock. These calculations were completed with all other parameter values at their "best estimate" values shown on Large Table 1. Table 2 provides a comparison of results – increasing the proportion of recharge applied to the bedrock generally resulted in increases in estimated pit inflows. Estimated pit inflows shown in Table 2 are still well within the range simulated by GoldSim (Table 1).

Table 2 Comparison of groundwater inflow rates with varying recharge assumptions

		Percentage of Recharge Applied to Bedrock	Estimated Pit Inflow (gpm)
West Pit Year 20	K based on field data	10	40
	K based on field data	50	50
	MODFLOW K values	10	80
	MODFLOW K values	50	70
East Pit Year 11	K based on field data	10	432
	K based on field data	50	510
	MODFLOW K values	10	690
	MODFLOW K values	50	790

3.0 Simulation of the Partridge River

3.1 Intro/Background

Concern has been raised on how the Partridge River is simulated in the MODFLOW model. Specifically, it was pointed out that in some cases, elevations used to simulate the river did not always result in a downstream decrease in river stage. The Partridge River is represented in the Mine Site MODFLOW model with the River Package, with the river cell stage used for the baseline MODFLOW model assigned from a digital elevation model (DEM). Given the differences in the scale of the DEM and the scale of the model cells, this methodology of assigning river stage did not always produce a downhill gradient between upstream and downstream model cells.

In order to address this concern, a sensitivity analysis was conducted, which is described below. For this sensitivity analysis, the simulation of the river in the MODFLOW model was modified, the calibration was updated, and the predicative simulations run. The modifications to the model are presented in Section 3.2.1. The comparison of the new model predictions to the base case predictions is presented in Section 3.2.2.

3.2 Partridge River Sensitivity Analysis

3.2.1 Model Modifications

The Partridge River representation in the Mine Site MODFLOW model was modified to maintain a stream width of one cell and stage elevations consistently decreasing from upstream to downstream. The initial stage elevations were extracted from a DEM and then manually adjusted to slope downhill from upstream to downstream.

The model was recalibrated with a combination of manual and automated calibration in PEST. The recalibration produced a similar fit to the calibration targets as the base model, including a good fit to the

Partridge River baseflow targets. Model parameter values changed only slightly as a result of the recalibration. Details on the recalibration are provided in Attachment A.

3.2.2 Model Predictions

The recalibrated parameters and the new river package were imported into the Mine Site predictive models for operations and closure. As shown in Figure 3, the modeled pit inflows differed from baseline by a maximum of 2.9%, which is well within the limits of model accuracy. This sensitivity analysis demonstrates that the changes to the representation of the Partridge River in the model do not impact the model predictions of pit inflow.

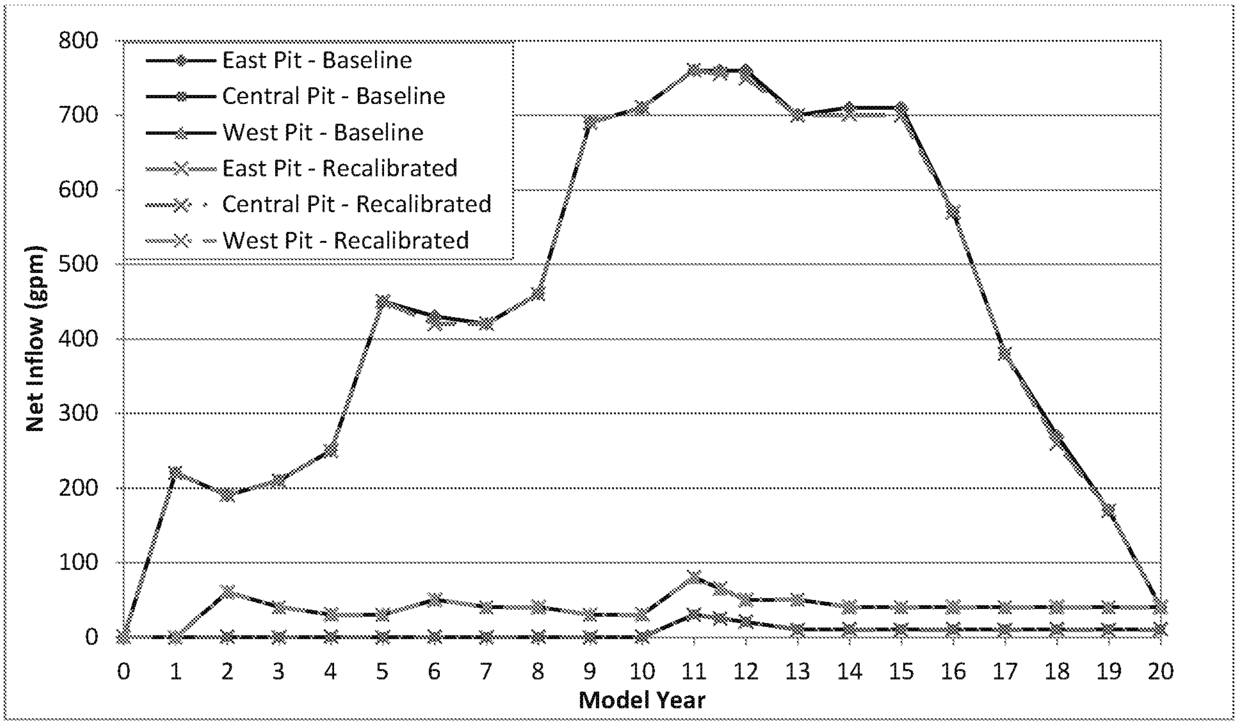

Figure 3 Comparison of groundwater inflow rates to the mine pits during operations

4.0 References

1. **Barr Engineering Co.** Response to Cooperating Agency Comments Related to Peter Mitchell Pit – Version 2 Technical Memo to Bill Johnson, Minnesota Department of Natural Resources. May 18, 2015.

2. **Poly Met Mining Inc.** NorthMet Project Water Modeling Data Package Volume 1 - Mine Site (v14). February 2015.

3. **Barr Engineering Co.** Hydrogeology of Fractured Bedrock in the Vicinity of the NorthMet Project (v3). December 2014.

4. **Lindholm, Gerald F.** Geology and Water Resources of the Hibbing Area, Northeastern Minnesota. *Hydrologic Investigations Atlas HA-280 (Sheet 2 of 3).* s.l. : Department of the Interior U.S. Geological Survey, 1968.

5. **Marinelli, Fred and Niccoli, Walter L.** Simple Analytical Equations for Estimating Ground Water Inflow to a Mine Pit. *Groundwater.* March-April 2000, Vol. 38, 2, pp. 311-314.

Large Tables

Large Table 1 - Inputs to Analytical Pit Inflow Calculations

Parameter	Description	Units	West Pit			East Pit			Basis for Value(s)
			Minimum	Best	Maximum	Minimum	Best	Maximum	
W_u	**distributed recharge flux** to unconsolidated material	in/yr	0.32	0.97	1.62	0.32	0.97	1.62	The total recharge applied to the model ranges from 0.36 in/yr and 1.8 in/yr (values used in the Mine Site MODFLOW model), with a best estimate of 1.08 in/yr (average of min and max). 90% of the recharge is applied to the unconsolidated material and 10% is applied to bedrock.
W_b	**distributed recharge flux** to bedrock	in/yr	0.04	0.11	0.18	0.04	0.11	0.18	
r_p	**effective pit radius**	feet	--	2108	--	--	1693	--	Calculated as the radius of a circle with the same area as the pit
K_{hu}	**horizontal hydraulic conductivity of the unconsolidated material**	feet/day	1.20E-02	2.43E-01	3.10E+01	1.20E-02	2.43E-01	3.10E+01	Minimum, geometric mean, and maximum of the nine aquifer test results reported in Phase I Hydrogeologic Investigation report
h_{0u}	**pre-mining saturated thickness of the unconsolidated material**	feet	--	10	--	--	10	--	Estimate of average uncosolidated material thickness based on site drilling data
h_{pu}	**saturated thickness at the pit walls in the unconsolidated material**	feet	--	0	--	--	0	--	Assumed value
K_{hDh}	**horizontal hydraulic conductivity of the Duluth Complex - calculations with K based on field data**	feet/day	2.60E-04	2.27E-03	4.10E-02	2.60E-04	2.27E-03	4.10E-02	Minimum, geometric mean, and maximum of the ten bedrock aquifer test results reported in Phase I Hydrogeologic Investigation report
K_{hVa}	**horizontal hydraulic conductivity of the upper Virginia Formation - calculations with K based on field data**	feet/day	--	--	--	2.40E-03	1.70E-01	6.80E-01	Minimum, geometric mean, and maximum of the aquifer test results reported in Phase II Hydrogeologic Investigation report
	horizontal hydraulic conductivity of the lower Virginia Formation - calculations with K based on field data	feet/day	--	--	--	8.00E-04	5.67E-02	2.27E-01	(1/3) * Hydraulic conductivity of upper Virginia Formation, consistent with onsite aquifer testing data
K_{hDh}	**horizontal hydraulic conductivity of the Duluth Complex - calculations with K from MODFLOW**	feet/day	2.60E-04	4.40E-04	4.10E-02	2.60E-04	4.40E-04	4.10E-02	Best estimate is the calibrated value from the MODFLOW model. Minimum and maximum from the ten bedrock aquifer test results reported in Phase I Hydrogeologic Investigation report.
K_{hVa}	**horizontal hydraulic conductivity of the upper Virginia Formation - calculations with K from MODFLOW**	feet/day	--	--	--	2.40E-03	3.10E-01	6.80E-01	Best estimate is the calibrated value from the MODFLOW model. Minimum and maximum from the aquifer test results reported in Phase II Hydrogeologic Investigation report.
	horizontal hydraulic conductivity of the lower Virginia Formation - calculations with K from MODFLOW	feet/day	--	--	--	8.00E-04	7.90E-02	2.27E-01	Best estimate is calibrated value from the MODFLOW model. Min and max = (1/3) * Hydraulic conductivity of upper Virginia Formation min and max, consistent with onsite aquifer testing data.
K_v/K_h	**hydraulic conductivity anisotropy ratio of the lower bedrock**	--	0.01	0.1	1	0.01	0.1	1	minimum and maximum ratio of vertical to horizontal hydraulic conductivity (K_v/K_h) were set at 1:100 and 1:1, respectively, with a best estimate set at 1:10

Large Table 1 - Inputs to Analytical Pit Inflow Calculations

Parameter	Description	Units	West Pit			East Pit			Basis for Value(s)
			Minimum	Best	Maximum	Minimum	Best	Maximum	
h_{pb}	**saturated thickness at the pit walls** in the bedrock	feet	0	330	650	0	330	650	The best estimate thickness value was set at half the pre-mining saturated thickness of the upper bedrock, described below. The minimum and maximum values represent maximum and very minimal drawdown, respectively.
h_{0b}	**pre-mining saturated thickness of the upper bedrock** (West Pit)	feet	--	660	--	--	--	--	Approximate premining groundwater elevation (1600 ft MSL) - bottom elevation of West Pit (940 ft MSL)
h_{0b}	**pre-mining saturated thickness of the upper bedrock** (East Pit)	feet	--	--	--	--	680	--	Approximate premining groundwater elevation (1600 ft MSL) - bottom elevation of West Pit (920 ft MSL)
d	**depth of the pit lake**	feet	--	0	--	--	0	--	Assumed value with no standing water at the bottom of the pit.

Attachment A

Partridge River Sensitivity Analysis

Modeling Details

The Base Case model used as the basis of this sensitivity analysis is the Mine Site MODFLOW model documented in Attachment B of the Water Modeling Data Package Volume 1 – Version 14. The objective of this analysis is to assess how changes in the simulation of the Partridge River effects the predicted groundwater inflow rates to the NorthMet mine pits during operations and closure.

1.0 Model Changes

The Partridge River representation in the Mine Site MODFLOW model was modified to maintain a stream width of one cell (Large Figure A-1) and stage elevations consistently decreasing from upstream to downstream. The total number of river cells used to represent the Partridge River was reduced from 1209 to 948.

The initial stage elevations were extracted from a DEM and then manually adjusted to slope downhill from upstream to downstream (Figure 1). River stage was linearly interpolated for model cells where the initial stage was higher than the upstream stage. For some upstream river cells, the stage was manually increased from the initial DEM value to maintain an average river stage similar to the average in the baseline model (Figure 2).

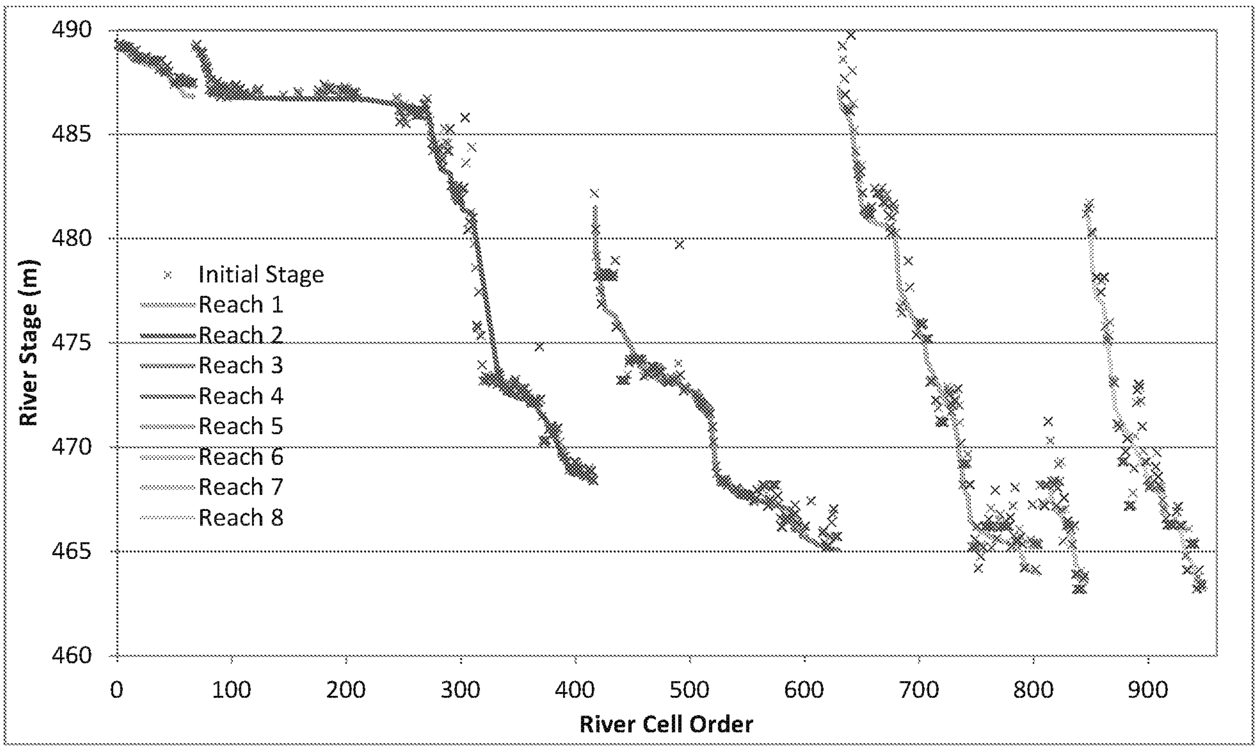

Figure 1. Comparison of initial and manually adjusted river stages in the Partridge River and its tributaries from upstream to downstream.

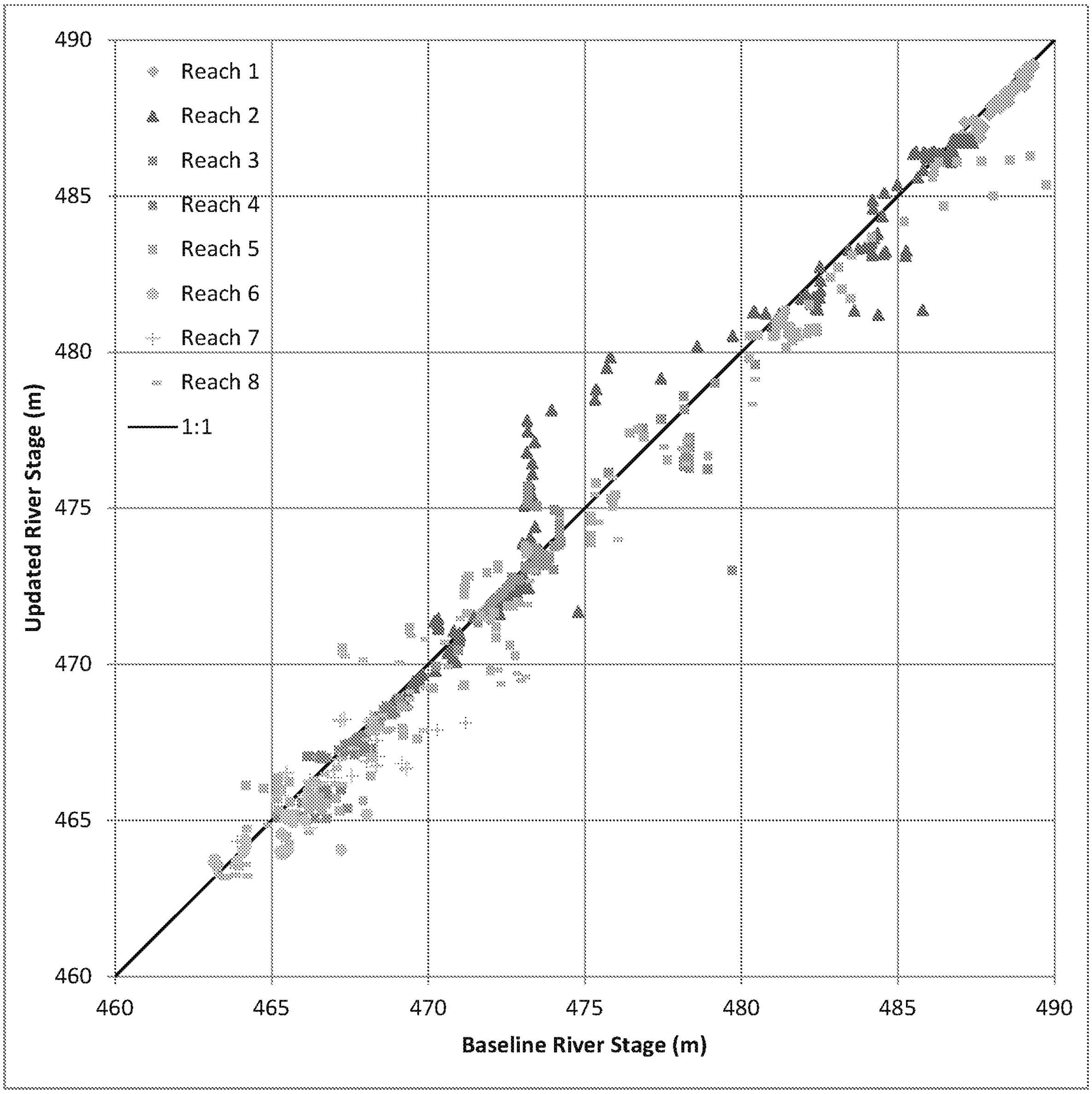

Figure 2. Plot of manually adjusted river stage vs. baseline river stage for model.

2.0 Model Recalibration

The groundwater flow model was run once with PEST to determine whether recalibration should be undertaken. The total objective function was 204, which is slightly higher than the baseline value of 153. Given the increase in the objective function, the decision was made to do a focused recalibration of the MODFLOW model prior to running the predictive simulations.

A combination of manual and automated calibration in PEST was used, which resulted in a total objective function of 157.6 (Table 1). Baseflow was not matched as well in the recalibration as in the baseline model, but the modeled baseflow values were still within 10% of the target values. The primary improvement to the objective function in the recalibration came from the targets for maintaining heads below ground surface.

Table 1. Comparison of calibration

	Baseline Calibration	Updated model, Recalibrated
Total objective function	153.12	157.59
Contribution to phi from observation group:		
head_ob	16.07	23.21
head_br	63.43	69.39
baseflow	0.64	17.82
bias	0.26	0.47
k_prior	14.11	14.31
k_regul	0.69	0.70
riv_kz_regul	0.18	0.19
gs_const	57.74	31.50

The vertical hydraulic conductivity components of Partridge River conductance were modified during the recalibration, with the values decreasing slightly for all reaches except reach 2 and reach 3 (Table 2; see Large Figure A-2 for reach locations).

Table 2. Comparison of the vertical hydraulic conductivity component of Partridge River conductance parameters

Parameter	Baseline value (ft/d)	Updated model, Recalibrated Value (ft/d)	Parameter Change (%)
kz_riv_1	41.0	39.6	-3.4
kz_riv_2	32.8	33.3	1.5
kz_riv_3	25.6	26.0	1.6
kz_riv_4	18.5	18.3	-1.2
kz_riv_5	13.2	12.9	-2.5
kz_riv_6	10.4	10.2	-2.1
kz_riv_7	8.8	8.6	-2.1
kz_riv_8	10.1	9.9	-1.6

Hydraulic conductivity parameters for surficial deposits were adjusted during recalibration, but hydraulic conductivity parameters for bedrock units were kept at baseline values in order to minimize unnecessary changes between the baseline model and the updated model (Table 3).

Table 3. Comparison of horizontal hydraulic conductivity parameters

	Baseline Value (ft/d)	Updated model, Recalibrated Value (ft/d)	Parameter Change (%)
Unconsolidated Glacial Deposits	Range: 0.056 - 167 Mean: 19.2	Range: 0.056 - 167 Mean: 19	Mean: -0.8
Unconsolidated Wetlands Deposits	Range: 0.0034 - 224 Mean: 23.7	Range: 0.0034 - 224 Mean: 23.4	Mean: -1.3
Giants Range Batholith	0.029	0.029	0.0
Biwabik Iron Formation	0.87	0.87	0.0
Upper Virginia Formation	0.31	0.31	0.0
Lower Virginia Formation	0.079	0.079	0.0
Duluth Complex	4.44E-04	4.44E-04	0.0

Three Partridge River baseflow estimates at SW002, SW003, and SW004 are included in the Mine Site MODFLOW model as calibration targets (Large Figure A-2). The baseflow targets are cumulative such that modeled baseflow at SW002 is included in the modeled baseflow at all downstream target locations. Baseflow in the recalibrated model was slightly overestimated at SW002 and SW004 compared to observations and the baseline calibration, but matched the observed baseflow at SW003 (Table 4).

Table 4. Comparison of baseflow

Target	Observed Baseflow (cfs)	Modeled Baseflow (cfs)	
		Baseline Calibration	Updated model, Recalibrated
sw002_baseflow	0.41	0.40	0.45
sw003_baseflow	0.51	0.51	0.51
sw004_baseflow	0.92	0.93	0.96

3.0 Model Predictions

The recalibrated parameters and updated river package were imported into the Mine Site predictive models for operations and closure of the NorthMet pits, and the models were rerun. Modeled pit inflows during operations differed by less than 10 gpm between the baseline and recalibrated models for the East Pit, but were equal at the Central and West Pits (Table 5). The modeled pit inflows in the baseline and recalibrated models differ 0 or 10 gpm in the Tables 5 through 7, because the values are rounded to the nearest 10 gpm. Rounding the MODFLOW pit inflow estimates to the nearest 10 gpm is consistent with what was done with the baseline MODFLOW estimates prior to input to GoldSim.

Table 5. Comparison of groundwater inflows to mine pits during operations in baseline and recalibrated models. All values in gallons per minute.

	East Pit		**Central Pit**		**West Pit**	
Year	***Baseline Model***	***Recalibrated Model***	***Baseline Model***	***Recalibrated Model***	***Baseline Model***	***Recalibrated Model***
0	0	0	0	0	0	0
1	220	220	0	0	0	0
2	190	190	0	0	60	60
3	210	210	0	0	40	40
4	250	250	0	0	30	30
5	450	450	0	0	30	30
6	430	420	0	0	50	50
7	420	420	0	0	40	40
8	460	460	0	0	40	40
9	690	690	0	0	30	30
10	710	710	0	0	30	30
11	760	760	30	30	80	80
12	760	750	20	20	50	50
13	700	700	10	10	50	50
14	710	700	10	10	40	40
15	710	700	10	10	40	40
*16**	*570*	*570*	*10*	*10*	40	40
17	*380*	*380*	*10*	*10*	40	40
18	*270*	*260*	*10*	*10*	40	40
19	*170*	*170*	*10*	*10*	40	40
20	*40*	*40*	*10*	*10*	*40*	*40*
2000	*90*	*80*	*10*	*10*	*40*	*40*

* Time series not used in GoldSim beyond Mine Year 15 for East and Central Pits and beyond Mine Year 20 for West Pit.

Modeled pit inflows during backfilling and closure differed by less than 10 gpm between the baseline and recalibrated models for the East Pit, but were equal at the Central and West Pits (Tables 6 and 7).

In summary, the analysis described above showed that changes to the way in which the Partridge River is simulated in the model do not impact the predictions of pit inflows.

Table 6. Comparison of groundwater inflows to East and Central pits during backfilling and closure in baseline and recalibrated models. All values in gallons per minute.

	East Pit		Central Pit	
Water Surface Elevation	***Baseline Model***	***Recalibrated Model***	***Baseline Model***	***Recalibrated Model***
1260	730	720	10	10
1360	710	700	10	10
1435	710	700	< 10	< 10
1485	570	570	< 10	< 10
1530	320	310	< 10	< 10
1565	190	190	< 10	< 10
1592	30	20	< 10	< 10
1595	20	10	< 10	< 10

Table 7. Comparison of groundwater inflows to West pit during backfilling and closure in baseline and recalibrated models. All values in gallons per minute.

	West Pit	
Water Surface Elevation	***Baseline Model***	***Recalibrated Model***
940	50	50
1000	50	50
1100	50	50
1200	50	50
1320	50	50
1450	50	50
1579	30	30
1585	30	30

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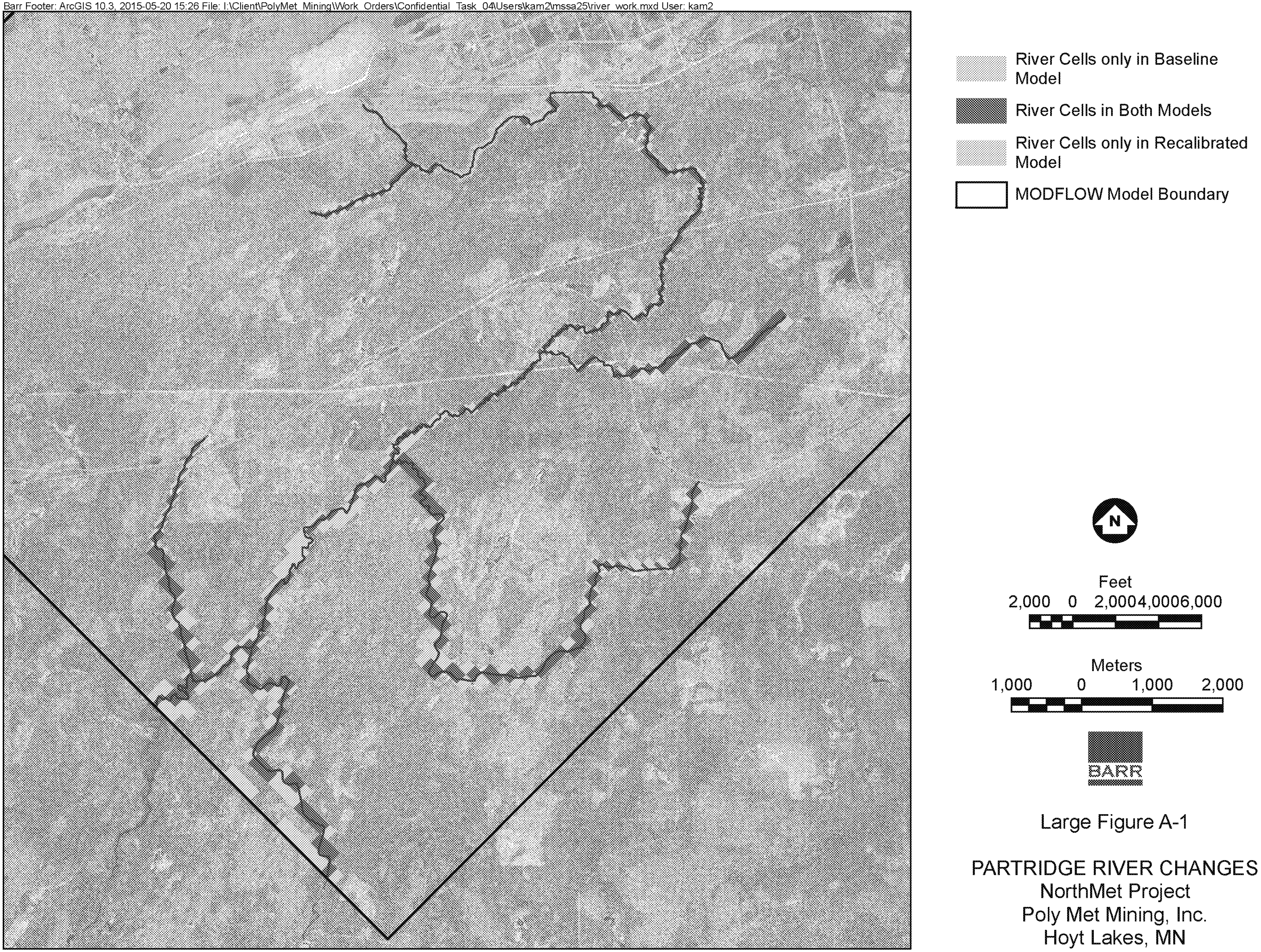

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PARTRIDGE RIVER CHANGES
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Poly Met Mining, Inc.
Hoyt Lakes, MN

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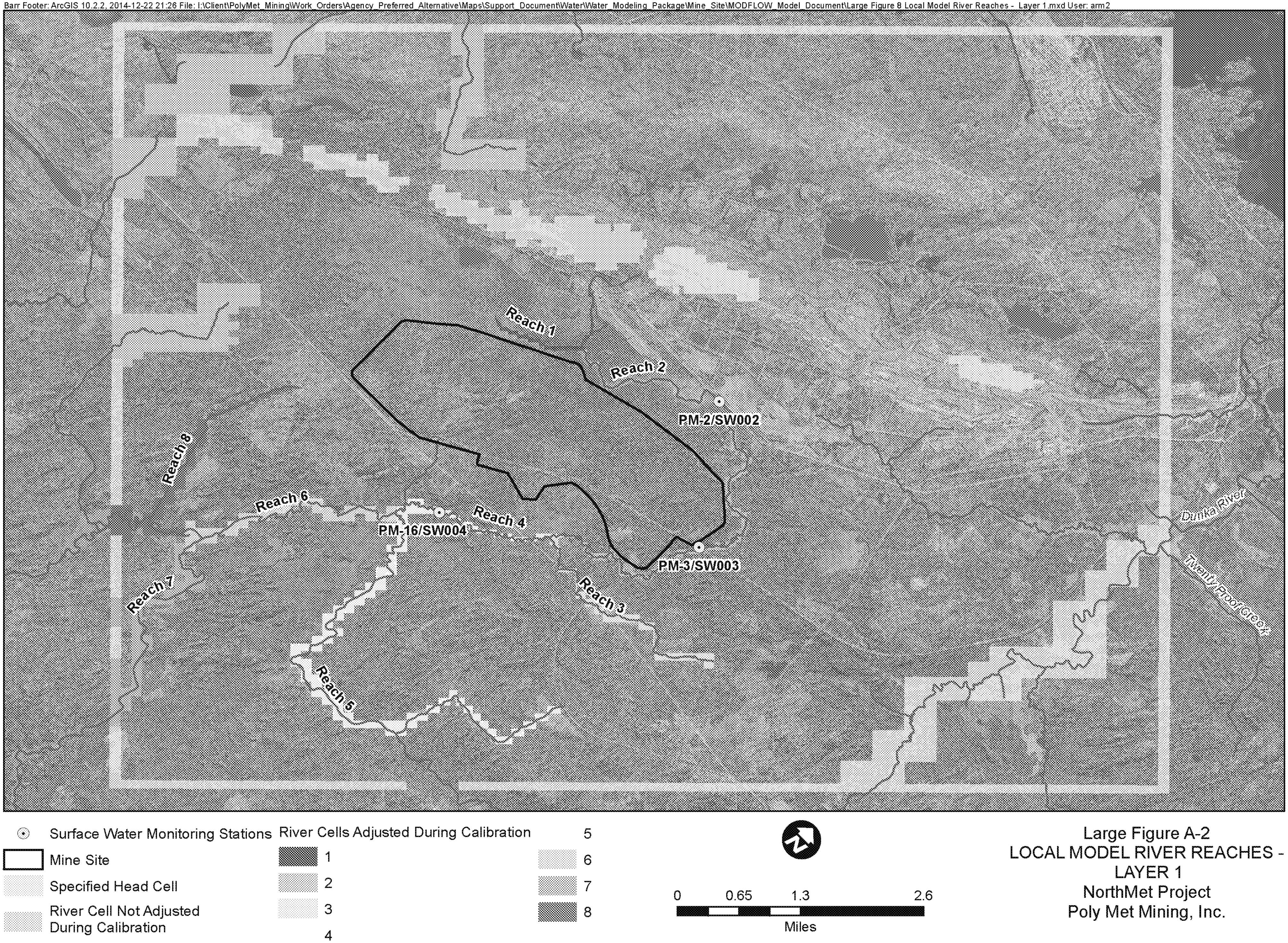

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LOCAL MODEL RIVER REACHES - LAYER 1
NorthMet Project
Poly Met Mining, Inc.